

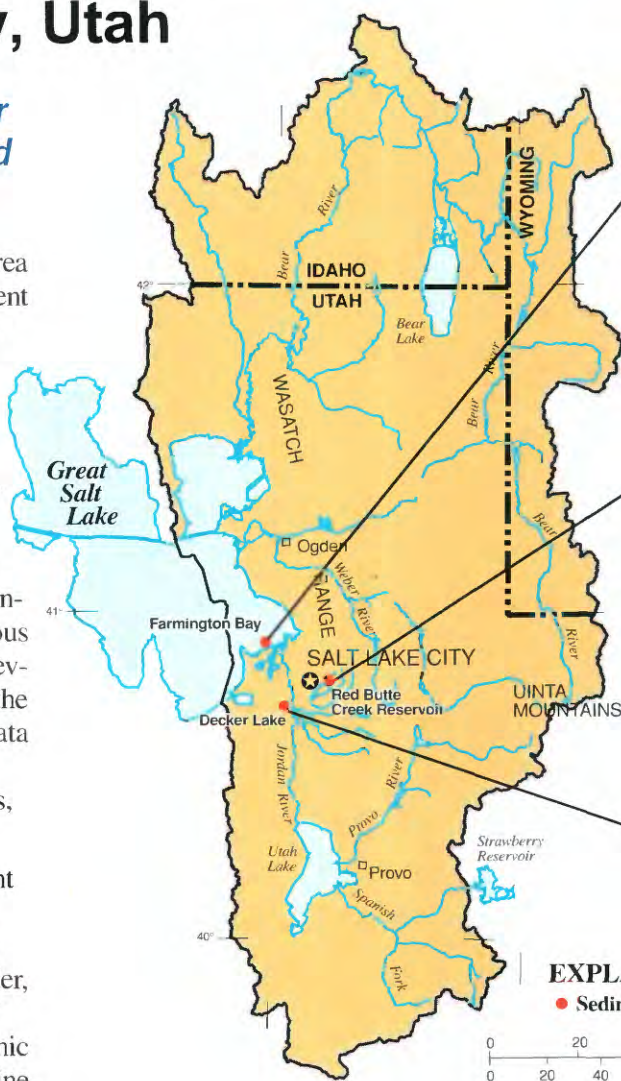
## NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

# Reconstructing Historical Changes in the Environmental Health of Watersheds by Using Sediment Cores from Lakes and Reservoirs in Salt Lake Valley, Utah

### *Long-Term Trends in Water Quality Can Be Determined by Using Sediment Cores*

The Great Salt Lake Basins study area of the National Water-Quality Assessment (NAWQA) program, which began in 1997, is increasing the scientific understanding of factors that affect surface-water quality within the study-area boundaries (fig. 1). One way to improve the understanding of these factors is to look at historical trends in existing water-quality data. Unfortunately, short record lengths, inconsistent analytical methods, numerous measurements at less than detection levels, and questionable accuracy limit the usefulness of historical monitoring data for most trace inorganic and organic contaminants found in streams, rivers, and lakes in the study area.

Collection and analysis of sediment cores from lakes and reservoirs may provide a record of long-term water-quality trends (Van Metre and Callender, 1996). Measurable concentrations of most trace elements and selected organic compounds are often associated with fine sediments in the water column. The sediments are continuously deposited in the bottom of lakes and reservoirs. Like reading the pages of a history book, analyzing the chemical composition of each sediment layer is a way to reconstruct historical changes in the quality of water entering a lake or reservoir. The objective of this fact sheet is to describe how cores were used to reconstruct historical changes in surface-water quality at three sites within the study area.



**Figure 1.** Sediment-core sites within the Great Salt Lake Basins/National Water-Quality Assessment study area, Utah.

### *Sediment Cores Were Collected From Three Sites In or Near Salt Lake City*

Sediment cores were collected from Farmington Bay (of Great Salt Lake), Decker Lake, and Red Butte Reservoir during April 1998 (fig. 1) by using a boat and specialized coring equipment

(fig. 2). Cores, as much as 95 centimeters (cm) in length, were collected with a gravity-coring device. Multiple sediment cores were collected at each coring site to obtain enough sample for organic and inorganic analysis. A box corer was used to collect shallow cores, less than 30 cm in length. The gravity coring device tends to compress the sediment core relative to the box coring device. This compress-





Photo courtesy of Chris Braun, U.S. Geological Survey, Austin, Texas.

## Farmington Bay and Decker Lake

Both the Farmington Bay and Decker Lake sites receive drainage from within the Jordan River Basin. The Jordan River originates as outflow from Utah Lake (fig. 1) and flows north about 66 kilometers (km) before it empties into Farmington Bay. The Jordan River has a drainage area of 9,040 square kilometers (km<sup>2</sup>) prior to entering Farmington Bay. The Jordan River receives runoff from most of the Salt Lake Valley, which is highly developed. The population of Salt Lake County, within Salt Lake Valley, has increased from 213,700 people in 1940 to more than 840,000 people in 1999 (Utah Population Estimates Committee, 1999). Population growth increases urban development and the number of potential sources of water contamination. Historical sources of contamination to the Jordan River include irrigation return flows, wastewater-treatment plants, storm runoff from urban areas, and discharge from industrial and mining facilities (Stephens, 1984).

The Decker Lake site is located southwest of Salt Lake City, about 22 km south of Farmington Bay. Decker Lake is small (0.13 km<sup>2</sup> maximum surface area) in size and receives storm runoff from approximately 25.4 km<sup>2</sup> of urban lands (Salt Lake County, 1999). The predominant land use within the Decker Lake watershed is classified as medium density residential (5 to 12 single family homes per 0.005 km<sup>2</sup>). Decker Lake also receives discharge from four irrigation canals, which accounts for most of the non-storm discharge to the lake (Salt Lake County, 1999). Outflow from Decker Lake is discharged to the Jordan River.

## Red Butte Reservoir

Red Butte Reservoir was constructed in the 1930s to create a water supply for military personnel at Ft. Douglas, which is located east of Salt Lake City (fig. 1). Red Butte Reservoir receives water from the Red Butte Creek drainage area located in the foothills of the Wasatch Mountains, east of Salt Lake City. The Red Butte Reservoir drainage basin is small (18.9 km<sup>2</sup>) and the land

is undeveloped. Because of the undeveloped nature of the watershed, the June Sucker, an endangered fish species that was native to Utah Lake, was recently transplanted into Red Butte Reservoir (Wolf, 1998).

## Statistical Tools Are Useful in Determining Historical Changes in the Environmental Health of a Watershed

The environmental health of a watershed depends on numerous chemical constituents, not on the concentration of any one single element. Trace amounts of selected chemical constituents, such as Cr and V, can be derived from both natural and artificial sources (for example, rock weathering and dumping of hazardous waste). Unfortunately, there is no single probe that can directly measure the environmental health of a watershed. Instead, the concentrations of multiple chemical constituents are measured, and this large multivariate data set is used to reconstruct historical changes in the environmental health of a watershed.

A statistical procedure called pattern-recognition modeling (Meglen and Sistko, 1985) can be used to monitor the environmental health of a watershed (fig. 3). Pattern-recognition analytical techniques enhance the interpretation of multivariate databases such as the one generated from the sediment cores collected and analyzed in the NAWQA program (fig. 1). Ideally, pattern-recognition modeling uses statistical and graphical techniques to separate the natural and human-caused processes that control observed variations in the chemistry of the lake or reservoir sediment samples. Once the different chemical fingerprints have been identified for the natural and human-caused sources, pattern-recognition analytical techniques can be used to reconstruct and monitor historical changes in the environmental health of the selected watershed. A detailed description on methods used for pattern-recognition modeling can be found in Naftz (1996).

**Figure 2.** Equipment used to collect lake and reservoir sediment cores.

sion can result in different ages for the same sample depths when comparing gravity and box cores collected at the same site.

After collection, a physical description of each core was completed. The core was then subsampled in discrete horizontal slices and analyzed for selected inorganic chemical constituents including aluminum (Al), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), silicon (Si), titanium (Ti), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), lithium (Li), manganese (Mn), arsenic (As), nickel (Ni), lead (Pb), scandium (Sc), strontium (Sr), vanadium (V), zinc (Zn), total carbon (C), organic carbon (OC), and nitrogen (N). The analytical methods used to process and analyze the lake sediment samples for these inorganic constituents are described in Van Metre and Callender (1996).

Each of the three sediment-core sites represents a different set of physical and chemical characteristics in its respective watershed. Currently (2000), the Farmington Bay and Decker Lake watersheds are dominated by urban land use and the Red Butte Reservoir watershed is mostly undeveloped. Specific characteristics of each watershed are described in the following sections.





**Figure 3.** Pattern-recognition modeling can be used like a thermometer to measure the environmental health of a watershed.

### ***Pattern-Recognition Analysis of Lake Sediment Data Identifies Sampling Layers Affected by Human-Caused Contamination***

A plot showing the results of the pattern-recognition modeling of the inorganic data generated from the lake sediment database is shown in figure 4. The two axes are linear combinations of the original multivariate data set consisting of 26 variables and 64 samples and can be thought of as a new set of plotting axes. Instead of each axis representing the concentration of a particular trace metal or other inorganic constituent, each axis represents combinations of the different chemical constituents in the lake sediments, thereby representing a geochemical property or process of potential interest (affected by the type and amount of numerous chemical constituents).

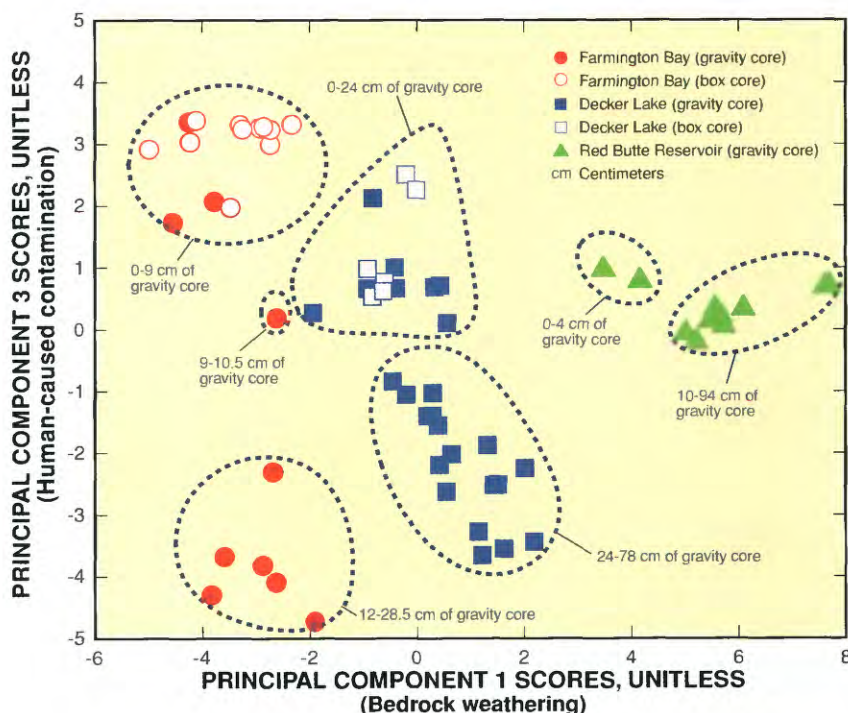
The suite of chemical constituents contained in each plotting axis can be used to determine what watershed property is represented (for example, pollution or natural weathering of geologic materials). The X axis in figure 4 (referred to as principal component 1 (PC 1)) represents the chemical composition of sediments derived from natural weathering of bedrock material in the watershed. Chemical constituents making a substantial positive contribution to the X axis

include Al, Fe, K, Si, Ti, Cr, Co, and V (table 1). For example, the association of Al, Fe, K, Si, and Ti in PC 1 can be associated with granitic rocks that occur in all three watersheds. The Y axis in figure 4 (referred to as principal component 3 (PC 3)) represents a suite of chemical constituents caused by human activities in the watersheds. Chemical constituents making a substantial positive contribution to PC 3 include Cu, Cd, Pb, Zn, total C, OC, P, and N (table 1). The geochemical association of Cu, Pb, and Zn in PC 3 is probably indicative of industrial activities or urban street runoff within the Farmington Bay and Decker Lake watersheds. In addition, Pb can also be associated with the combustion of leaded fuel and Cd can be a byproduct of smelting operations. Elevated concentrations of P and N are probably associated with fertilizers as well as wastewater discharge and urban runoff in the drainage basin. The geochemical significance of the chemical constituents making a substantial

positive or negative contribution to PC 2 is not apparent (table 1), and therefore is not shown in figure 4.

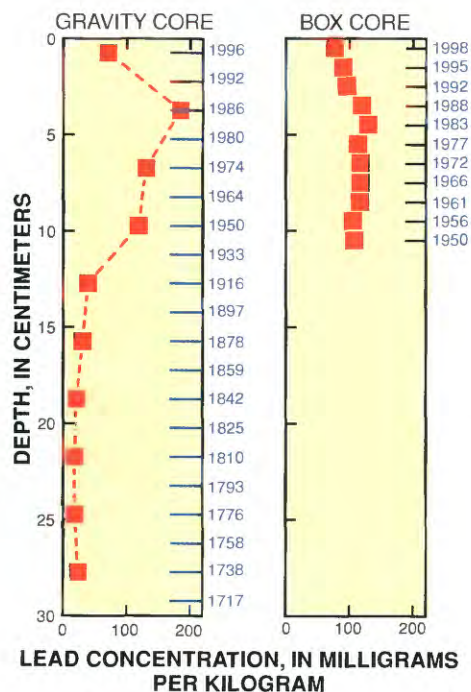
The individual points in figure 4 represent where individual sediment samples plot on these newly defined axes. Samples from each of the three coring sites show distinct groupings in their PC 1 scores (natural bedrock weathering). Sediment samples from Red Butte Reservoir have the largest PC 1 scores, indicating that natural weathering is an important process in this watershed. The watershed above the Red Butte Reservoir coring site is non-urban and is located within the boundaries of Wasatch National Forest. Both of these factors will enhance the natural weathering chemical fingerprint that is observed. In contrast, the Farmington Bay and Decker Lake coring sites have low PC 1 scores, indicating less influence from bedrock weathering in the sediment chemistry. Both coring sites are within the Jordan River watershed that contains large amounts of urban development.

Samples from each of the three coring sites also show distinct groupings in their PC 3 scores (contamination from human activities) (fig. 4). Sediment samples near the surface of each core (younger sediments) have the highest PC 3 scores indicating the largest amount of contam-



**Figure 4.** Principal component 1 and 3 scores for sediment-core data collected from sites in and adjacent to Salt Lake City, Utah.





**Figure 6.** Lead concentration compared to sample depth and estimated date of sediment deposition in the gravity- and box-core data collected from Farmington Bay, Utah.

## Sources of Additional Information

Callender, E., and Van Metre, P.C., 1997, Reservoir sediment cores show U.S. lead declines: *Environmental Science and Technology*, v. 31, no. 9, p. 424-428.

Meglen, R.R., and Sistko, R.J., 1985, Evaluating data quality in large data bases using pattern-recognition

techniques, in Breen, J.J., and Robinson, P.E., eds., *Environmental Applications of Chemometrics*, American Chemical Society Symposium Series 292, American Chemical Society, Wash., D.C., p. 18-33.

Naftz, D.L., 1996, Pattern-recognition analysis and classification modeling of selenium-producing areas: *Journal of Chemometrics*, v. 10, p. 309-324.

Nagpal, N.K., 2000, Ambient water quality criteria for polycyclic aromatic hydrocarbons (PAHs), Overview report: accessed July 27, 2000, at URL: <http://www.elp.gov.bc.ca/wat/wq/BCguidelines/pahs.html>

Salt Lake County, 1999, Decker Lake clean lakes grant: Project summary reports 1998-1999: Salt Lake County Department of Public Works/Engineering Division Report, unnumbered pages.

Stephens, D.W., 1984, Water-quality investigations of the Jordan River, Salt Lake County, Utah, 1980-82: U.S. Geological Survey Water-Resources Investigations Report 84-4298, 45 p.

Utah Population Estimates Committee, 1999, Yearly population of Salt Lake County, 1940-1999: accessed August 8, 2000, at URL: <http://www.governor.state.ut.us/dea/qget/1.htm>

Van Metre, P.C., and Callender, E., 1996, Identifying water-quality trends in the Trinity River, Texas, USA, 1969-1992, using sediment cores from Lake Livingston: *Environmental Geology*, v. 28, no. 4, p. 190-200.

Van Metre, P.C., and Callender, E., 1997, Water-quality trends in White Rock Creek Basin from 1912-1994 identified using sediment cores from White Rock Lake Reservoir, Dallas, Texas: *Journal of Paleolimnology*, v. 17, p. 239-249.

Van Metre, P.C., Mahler, B.J., and Furlong, E.T., 2000, Urban Sprawl Leaves Its PAH Signature: *Environmental Science & Technology*, v. 34, no. 19, p. 4064-4070.

Wolf, J., 1998, Nobody gives a damn about this dam: *High Country News*, v. 30, no. 8, accessed August 8, 2000, at URL <http://www.hcn.org/1998/apr27/dir/Hots308.html>.

## National Water-Quality Assessment Program

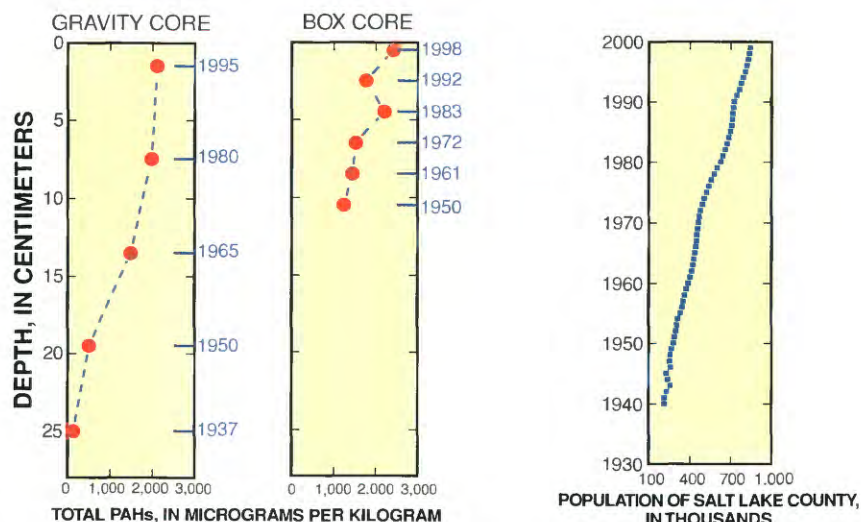
The Great Salt Lake Basins study unit is 1 of 50 study units involved in the USGS NAWQA program. The goals of the NAWQA program are to describe the status and trends in the quality of the Nation's ground- and surface-water resources and to gain a better understanding of the natural and human factors that affect the quality of these resources. The study design balances the unique assessment requirements of individual hydrologic systems with a nationally consistent design structure that incorporates a multi-scale, interdisciplinary approach.

## Information on the NAWQA Program can be obtained from:

Great Salt Lake Basins NAWQA Chief  
U.S. Geological Survey  
2329 Orton Circle  
Salt Lake City, UT 84119-2047

<http://ut.water.usgs.gov>

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**Figure 7.** Vertical distribution of total polycyclic aromatic hydrocarbons (PAHs) concentration in gravity- and box-core data collected from Farmington Bay, Utah, compared to population growth in Salt Lake County, Utah. The gravity core analyzed for PAHs is different from the gravity core analyzed for trace metals.



**Table 1.** Principal component loadings of each chemical constituent on the first three principal components used in the pattern-recognition modeling of the sediment-core data collected from sites in or adjacent to Salt Lake City, Utah. Loadings highlighted in yellow are greater than 0.20 or less than -0.20. This cutoff value best explains the most probable geochemical processes controlling the elemental distribution in each principal component.

Chemical constituent	Principal component 1 loadings, unitless	Principal component 2 loadings, unitless	Principal component 3 loadings, unitless
Aluminum	0.295254	0.072878	0.017907
Arsenic	-0.089463	0.317490	0.092920
Barium	0.149882	0.075695	-0.241670
Cadmium	0.042169	0.106878	0.363157
Calcium	-0.255595	0.079353	-0.144399
Chromium	0.269251	0.098898	0.038749
Cobalt	0.242171	0.018246	0.087209
Copper	-0.106718	-0.201915	0.301743
Iron	0.306469	-0.059670	0.059985
Lead	-0.156224	-0.194333	0.224212
Lithium	-0.064312	0.387471	-0.047665
Magnesium	-0.072929	0.369144	0.022338
Manganese	0.117342	0.339836	0.026355
Nickel	0.159522	0.291293	0.112164
Nitrogen	-0.034114	0.139513	0.341867
Organic carbon	0.007021	0.094486	0.358203
Phosphorus	0.160274	0.204692	0.269909
Potassium	0.286406	0.064733	0.034939
Scandium	0.119770	-0.339673	0.116128
Silicon	0.258451	-0.020030	-0.126773
Sodium	-0.211878	0.234843	-0.007193
Strontium	-0.284606	-0.037571	-0.012545
Titanium	0.282458	-0.078169	-0.064077
Total carbon	-0.168397	0.012603	0.278211
Vanadium	0.282487	-0.115805	0.119622
Zinc	-0.042597	-0.158072	0.406199

ination from human activities in each watershed. The deeper sections of each core (older sediments) have the smallest PC 3 scores, indicating little or no contamination from human activities (fig. 4). Shallow sediment samples from Red Butte Reservoir have lower PC 3 scores than the shallow sediment samples from either Farmington Bay or Decker Lake. This trend is consistent with urban development in the Jordan River watershed (Farmington Bay and Decker Lake coring sites).

### *Shallow Lake Sediment Samples Exhibit Elevated Levels of Human-Caused Contamination*

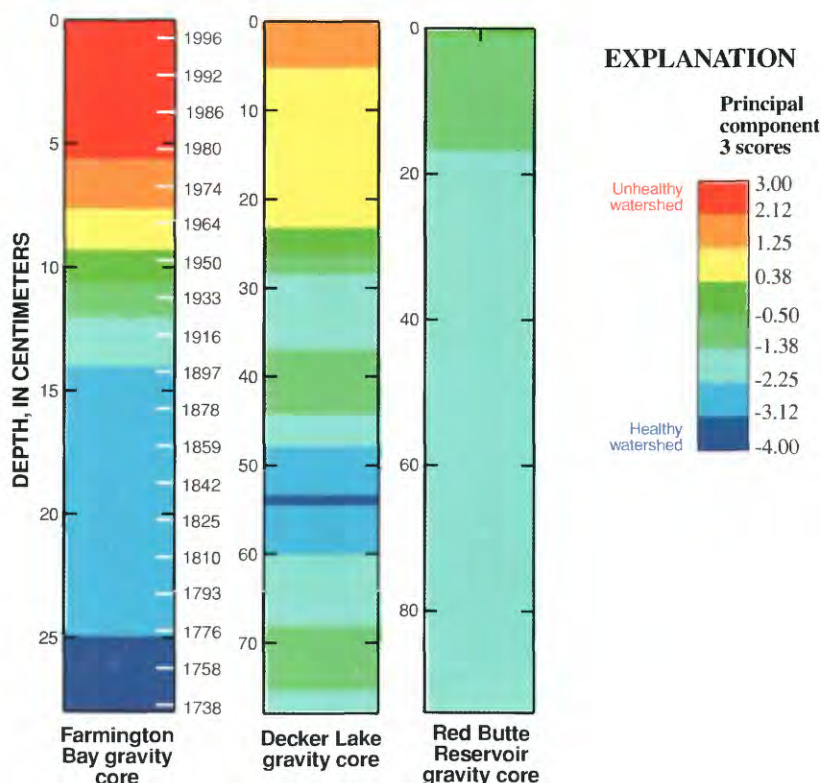
Vertical profiles of PC 3 scores from each of the gravity cores (fig. 5) were used to compare historical changes in the relative environmental health of each watershed. To correlate historic changes in land use to changes in the sediment-core chemistry,

an attempt was made to age-date each sediment sample by measuring the concentration of cesium-137 (Cs-137) and lead-210 (Pb-210), both radioactive isotopes. Increased concentrations of Cs-137 in the atmosphere (eventually deposited on the land surface) were caused by above-ground nuclear testing. Measurable concentrations of Cs-137 first appeared in the atmosphere during 1952 and peaked during 1963-64. Lead-210 is a naturally occurring radioactive isotope that is useful for dating sediments from 100 to 200 years old. The analytical method used to determine Cs-137 concentrations in sediment samples is described by Van Metre and Callender (1997). Reliable age dates could only be determined in the sediment core from Farmington Bay (fig. 5); however, the non-dated sediment cores from Decker Lake and Red Butte Reservoir can be used to evaluate generalized historical trends in watershed health.

The 28-cm sediment core collected from Farmington Bay contains sediment deposited during the past 260 years (fig. 5). On the basis of the vertical profile of PC 3 scores, deposition of contaminated sediments began to occur sometime in the early to mid-1900s (fig. 5) and has become progressively greater in recently deposited sediments. The most highly contaminated sediments were deposited from 1979-98 (fig. 5). Beginning in the early 1900s and continuing back to about 1730 (the bottom of the core), uncontaminated sediments were deposited in Farmington Bay. These trends are most likely correlated with the history of development in Salt Lake Valley.

Similar to Farmington Bay, the sediment core from Decker Lake has the largest amount of contamination in the most recently deposited sediments in the upper 5 cm of the core (fig. 5). The degree of sediment contamination gradually decreases from 5 to 36 cm below the water/sediment interface. Below 36 cm, the sediments show little contamination; however, small sections of more contaminated sediments were found. Dredging operations in Decker Lake during 1994 (Salt Lake County, 1999) did not occur at the coring site; however,





**Figure 5.** Vertical distribution of principal component 3 scores in gravity-core data collected from Farmington Bay, Decker Lake, and Red Butte Reservoir, Utah. Top of core corresponds to 1998.

dredging may have re-suspended a mixture of contaminated and uncontaminated bottom sediments that were then redeposited at the coring site. In addition, dredge mixing away from the coring site and redeposition of these sediments at the coring site may have masked the identification of the Cs-137 peak and diluted near-surface core sections with relatively uncontaminated sediments from deeper sections of the sediment column.

The sediment core from Red Butte Reservoir contains slightly contaminated sediments in the top 18 cm followed by uncontaminated sediments from 18 to 94 cm below the water/sediment interface (fig. 5). This observation is not surprising because the watershed above the coring site is mostly undeveloped. Age-dating of the sediments was not possible; however, the Cs-137 profile indicates that the entire core probably consists of sediments deposited on or after 1964. Because the watershed above Red Butte Reservoir is mostly undeveloped, the source of contamination in the top 18 cm of the core is unknown. Possible contaminant sources

could include atmospheric deposition of contaminants in the watershed.

### *Declining Lead Concentrations Observed in Recent Lake Sediments From Farmington Bay*

The vertical profile of Pb concentration in samples from the gravity and box cores collected from Farmington Bay indicates declining Pb concentrations since the early to mid-1980s (fig. 6). Recent sediments from both cores (deposited during 1996-98) indicate a 41- to 62-percent reduction in Pb concentration compared to the peak Pb concentrations in sediment deposited during the mid-1980s. These trends are in general agreement with results from Callender and Van Metre (1997) that found decreasing concentrations of Pb in recent samples (since the mid-1970s) from sediment cores collected at four sites in the eastern half of the United States. The decrease in Pb concentration in both cores from Farmington Bay probably reflects the 98-percent

reduction in Pb emissions to the atmosphere since 1972 (Callender and Van Metre, 1997).

Although Pb concentrations in lake sediments from Farmington Bay have decreased since the mid-1980s, elevated concentrations of Pb still remain. The Pb concentration in sediments deposited prior to the late 1800s was less than 30 milligrams per kilogram (mg/kg) (fig. 6). Lake sediments deposited during the mid- to late 1990s contained Pb concentrations more than twice the baseline concentration. Although Pb concentrations have shown recent declines, it is apparent from the lake-core data that sediment with Pb concentrations exceeding predevelopment baseline values are currently (2000) being deposited in Farmington Bay.

### *Farmington Bay Sediment Core Indicates Increasing Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs)*

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic compounds that are combustion products from sources such as automobiles, airplanes, and fires. Some PAHs, such as acridene, can be toxic at elevated concentrations (Nagpal, 2000). Lake sediment samples from Farmington Bay were analyzed for total PAHs by using the analytical method described in Van Metre and others (2000). Total PAHs in sediment cores from Farmington Bay consistently increase from near 0 micrograms per kilogram ( $\mu\text{g/kg}$ ) in sediments deposited before 1940 to more than 2,000  $\mu\text{g/kg}$  in selected sediment layers deposited after the early to mid-1980s (fig. 7).

A positive correlation exists between population growth in Salt Lake County and the PAH concentrations measured in the lake sediments from Farmington Bay (fig. 7). This correlation indicates that the most likely sources of PAHs in lake sediments deposited since 1940 are probably derived from human-induced combustion products.